

A COMPARISON OF MILITARY ELECTRONIC APPROACH PLATE FORMATS

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ABSTRACT

Electronic approach plate formats were compared to determine which facilitated the best pilot performance when flying precision and non-precision approaches. Four formats which varied in map orientation and color scheme were flown: monochrome north-up, monochrome track-up, color north-up, and color track-up. Although results revealed a statistically significant difference favoring the track-up orientation in the non-precision approaches, the differences were so small that they showed no practical impact on performance. However, when given their choice of which format to fly, pilots overwhelmingly flew a color map format. In addition, half of the pilots flew a map orientation of north-up and half flew track-up.

INTRODUCTION

Instrument approach procedures (IAP) are designed to provide a descent from the enroute environment to a point where a safe landing, or if necessary, a missed approach, can be made. Currently, IAP information is presented in paper format and is published and distributed by both government and commercial cartographers as instrument approach charts. The Defense Mapping Agency (DMA) provides a complete set of military charts for the United States airspace which consists of 16 bound booklets, 5 inches x 8 inches, with each booklet containing approximately three hundred pages (U.S. Department of Transportation, 1993). The complete set of military charts is revised on an eight week cycle. The commercially distributed charts, primarily distributed by Jeppesen Sanderson, are revised on an as required basis (U.S. Department of Defense, 1993). Depending on flight plan requirements, pilots may be tasked with carrying many if not all of these books. Although pilots may only use one of these books during the approach, storage of multiple books is necessary in an already crowded cockpit.

The paper charts, which are black text on a white page, provide pilots with the aeronautical data required to execute instrument approaches to airports. Each procedure is designated for use with a specific electronic navigational aid, such as an instrument landing system (ILS), VHF omnidirectional radio range (VOR), global positioning system (GPS) or tactical air navigation (TACAN).

The size of the charts forces the symbology and text to be quite small in order to accommodate all the information. Fear of litigation and liability often precludes cartographers from removing marginally useful information from the charts; as a result, current IAPs tend to be information dense.

Electronic approach plates (EAPs) offer a more flexible medium to present approach information to the

aircrew (Mykityshyn, Kuchar, and Hansman, 1994). Databases could be used to provide the information to construct the format in real time in the cockpit. Instead of making revisions to a complete set of manuals, only the database would be affected by changes. Since the database is a computer software item, it could easily and inexpensively be updated.

Due to resolution limitations of current electronic displays, larger type fonts and symbol sizes than are currently used on the paper charts would be required to improve symbol legibility (Clay and Barlow, 1994). However, any increased size of the symbology results in increased clutter on information dense charts. Decluttering techniques or format modifications will be required for electronic charts. For instance, color and the use of a zooming capability could be added to the electronic displays to declutter the symbology.

Another feature of electronic displays is their ability to provide dynamic formats, while the information on the paper charts must remain static. The approaches on the paper charts are all shown in a north-up orientation, regardless of the actual track the pilot is flying. Electronic displays can rotate the symbology, thus providing both north-up and track-up formats.

The issues of color scheme and map orientation have been evaluated in the civilian aircraft industry using commercial (Jeppesen) approach plates (Mykityshyn and Hansman, 1991; Mykityshyn et al., 1994; Hofer, Palen, Higman, Infield, and Possolo, 1992; and Hofer, Kimball, Pepitone, Higman, Infield, and Possolo, 1993). Because the military approach plates differ from Jeppesen plates, DMA wanted to evaluate some of the same issues, using their military approach plates, to facilitate the transition from paper approach plates to electronic formats in military aircraft. Therefore, DMA asked Wright Laboratory to evaluate color scheme and map orientation on military approach plates.

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OBJECTIVE

The purpose of this study was to compare pilots' performance using four versions of EAP formats. The elements of interest were color scheme and map orientation. The four combinations tested were: monochrome north-up, monochrome track-up, color north-up, and color track-up. A secondary objective was to investigate the use of a zooming capability to control the size of the viewing area, thus managing the amount of overall clutter on the EAP display formats. A third objective was to evaluate these formats in both precision and non-precision approaches because of the different instrument procedures used for each type of approach.

METHOD

Apparatus

Dynamic Cockpit. This study was conducted in a fixed-based, single seat, generic fighter cockpit evaluation tool which contained a single throttle and the limited-displacement control stick (Figure 1). An F-16 aeromodel was employed.

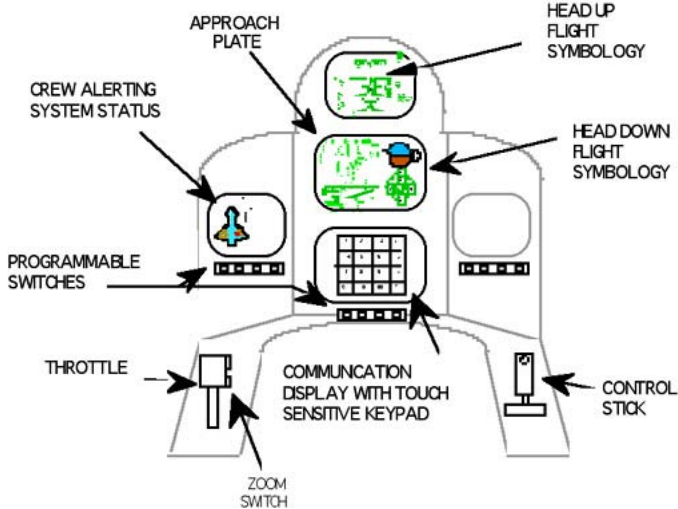


Figure 1. Cockpit.

Four of the five cathode ray tubes (CRTs) in the cockpit were utilized. The top CRT portrayed head-up flight symbology. The EAPs were positioned on the left 6"x8" portion of the center CRT. The center CRT also contained head down flight symbology on the right. The left CRT contained a crew alerting system status display with engine parameters. The bottom CRT employed a touch sensitive keypad used to change radio frequencies, and manipulate commanded altitudes and airspeed markers. Programmable switches were used to change navigation radios.

Display formats. Figure 2 shows an example of an EAP flown by the pilots during the study. The amount of

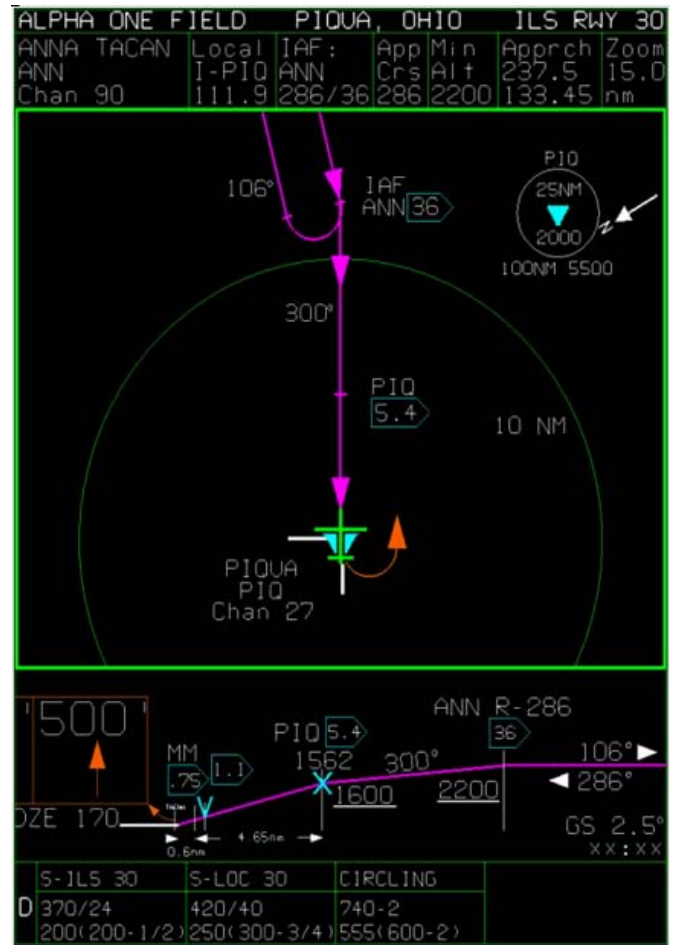


Figure 2. Electronic Approach Plate Format.

detail shown on the EAP was less than that on the paper charts, but all pertinent information was still present (Hofer et al., 1993). The plates were divided into three sections: two fixed data areas, a plan-view diagram, and a vertical profile diagram. The fixed data areas contained numerical data. The plan-view was a graphical look-down view of the entire approach. When the plan-view was viewed in the track-up mode, the text always remained upright as the map rotated around the fixed aircraft symbol in the center of the format. The vertical profile view was a side view of the approach and provided a graphical depiction primarily of altitude information.

In the monochrome version, all information was displayed in green on a black background. In the color version, colors recommended by the Federal Aviation Administration Advisory Circular 25-11 (1987) were used.

A continuous zoom function was provided so that subjects could change the range of display coverage. This allowed them to vary the amount of detail displayed on both the plan view and the profile view during different segments of the approach. Pilots could change the display range of either the plan view or the profile view by simply touching the corresponding section of the display and then using the zoom switch to change the range. The point about which the zoom focused in both the plan-view and the profile-view was the aircraft symbol.

Experimental Design

This study employed a mixed experimental design. The two within-subjects variables were color scheme (color and monochrome) and map orientation (north-up and track-up). The between-subjects variable was type of approach (precision and non-precision). All variables were presented in a counterbalanced order.

Dependent Variables

Flight Performance. Although a number of objective flight performance measures were collected, the ones of primary interest were: root mean square (RMS) airspeed deviations, RMS altitude deviations, and RMS course deviations.

Subjective Measures. Three types of situational awareness (SA) probe questions were asked while the subjects were flying the approaches: world referenced, ego referenced, and focused attention questions (Hofer et al., 1993). World referenced questions asked location/position of two fixed objects, such as, "Is PARKK NDB north of SEATTLE TACAN?". Ego referenced questions asked location/position of a object with respect to the pilot's aircraft, for instance, "Is the airport to the left of your position?". Focused attention questions asked single pieces of information, such as, "What is the touchdown zone elevation (TDZE)?" Time to respond, as well as accuracy of response was recorded.

Subject-pilots also completed questionnaires after each profile was flown. After all profiles were flown, the pilots filled out a final questionnaire. This questionnaire contained a Subjective WORKload Dominance (SWORD) technique (Vidulich, 1989), a performance ranking of the display formats, and the solicitation of overall comments on the electronic approach formats. SWORD enables a subjective comparison of the difference in workload experienced when flying the profiles using the various formats.

Pilots' Choice. Previous research (Mykityshyn et al., 1994) comparing various electronic versions of commercial paper approach procedures (Jeppesen) has shown little primary flight performance differences. Realizing that primary flight performance might not be sensitive to the versions of the EAPs compared, a key feature of this study was the "Pilot's Choice" profile. This profile measured pilots' preference of color scheme and map orientation by allowing pilots to select monochrome, color, north-up, and track-up anytime during the flight of a fifth profile. Pilots' Choice data were gathered in two segments: from initial approach fix to final approach fix, and from final approach fix to missed approach fix.

Subjects

Sixteen Air Force pilots flew approaches using the different formats. All were required to have a minimum of 300 hours flying time. The subject pool consisted of 6 pilots with primarily fighter experience, 8 pilots with bomber/cargo experience, and 2 pilots with experience in both fighter and transport aircraft.

Procedure

Sessions lasted approximately 3 hours. The subjects were briefed first in a classroom environment. Then they were briefed in the cockpit while becoming familiar with the cockpit layout and the procedures for flying the profiles. Next, they flew an approach using a paper approach plate. This allowed subjects to become familiar with the aeromodel and the SA probe questioning procedures. Subjects could practice with this approach more than once if needed.

An approach plate with characteristics of the first condition (the combination of color scheme and map orientation) was introduced to the subject statically; the aeromodel was not running, but all graphics were present. This briefing allowed the subjects time to review the approach procedure and simulated what they would have done during mission planning or while flying enroute.

When training on a specific static format was completed, pilots flew the approach for data collection. A portion of the questionnaire was filled out pertaining to that specific format. The other formats were tested in the same fashion. After all four formats were flown, pilots flew the Pilot's Choice profile with their choice of color scheme and map orientation. The initial presentation of this format was in monochrome and north-up, but using the programmable switches, pilots could change the color scheme and orientation anytime during the approach. Upon completion of all flying tasks, pilots filled out the remainder of the questionnaire.

RESULTS

Flight Performance

Objective data from this experiment were analyzed using the Statistical Package for the Social Sciences (SPSS). Bartlett's test of sphericity was not significant ($F(2,14) = 31.42, p < 0.198$) indicating independence of the performance measures, therefore, results were analyzed using ANOVA. Results showed a significant interaction between type of approach (precision/non-precision) and map orientation (north-up/track-up), in terms of the RMS airspeed deviation ($F(1,14) = 5.48, p < 0.035$) (Figure 3). Analysis of simple effects revealed significantly less airspeed error when using the track-up orientation than when using the north-up orientation in the non-precision condition. No other significant results were found.

Zoom Data. Based on a frequency count during various phases of the procedure, pilots manipulated the zoom function primarily enroute to the initial approach fix (IAF). On average, subjects manipulated the zoom function a total of 12 times during the "Start to IAF" portion of the flight, and 1.5 times for all other phases combined. Figure 4 shows the average map range that the pilots settled on for each segment of the procedure.

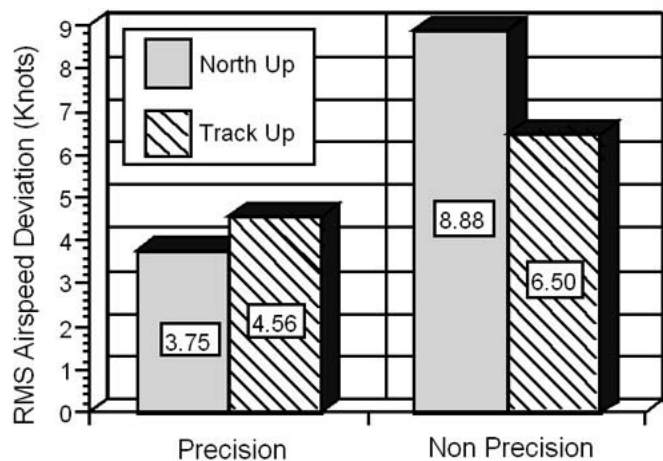


Figure 3. Interaction Between Type of Approach and Map Orientation.

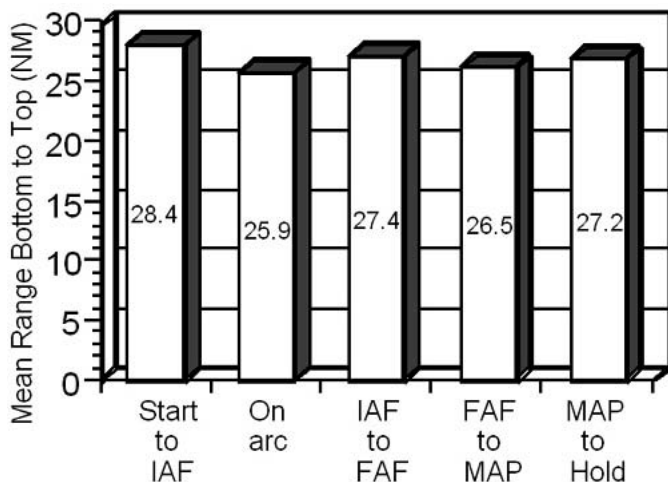


Figure 4. Map Range by Flight Segment

Subjective Measures

SA Probes. SA probe question data was scored by calculating the number of correct responses versus the number of questions asked. The focused attention questions were answered correctly 100% of the time. The world referenced questions were answered correctly 95.5% of the time. In all cases when a world referenced question was missed, the pilots were flying in the track-up mode (both monochrome and color versions). For the ego referenced questions, correct answers were given 98% of the time. The missed questions occurred when the pilots were flying in the monochrome north-up mode.

SWORD Data. The SWORD technique utilized a series of pair-wise comparisons between the various system configurations to determine which configuration elicited the most workload. The SWORD data were analyzed using a 2X2X2 Analysis of Variance with the two within subjects factors as repeated measures. The ANOVA results showed a significant effect for color scheme ($F(1,14) = 112.95$, $p < 0.001$). Figure 5 shows that subjective workload was found to be significantly higher with the monochrome display than with the color display.

Higher Workload

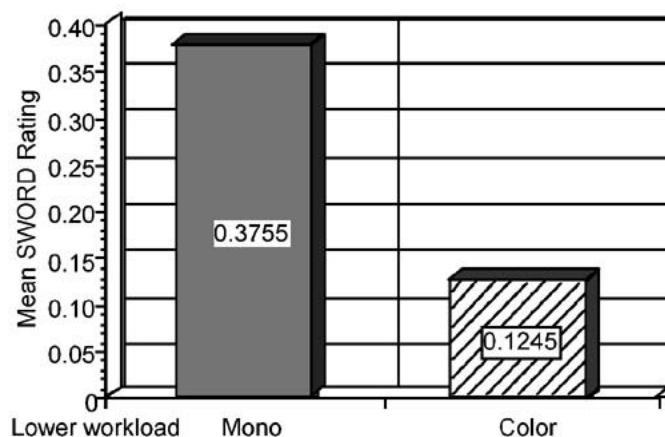


Figure 5. SWORD Main Effect for Color Scheme

Pilot's Choice

Results for the Pilots' Choice data revealed that half of the pilots flew north-up, half flew track-up, and all but one flew a color format.

DISCUSSION

Flight Performance

Although analysis of RMS airspeed error showed a statistically significant interaction between the map orientation variable and the type of approach variable, there was no practical difference in airspeed. For non-precision approaches, pilots had 2.38 knots less airspeed error when flying a track-up EAP than when flying an EAP in the north-up mode. Since pilots are normally required to maintain their airspeed -5 to +10 knots during an approach for a qualified grade during an instrument evaluation (US Air Force, 1994), the airspeed deviations are well within limits.

Zoom Data. Pilots primarily used the zoom capability in the initial phase of the procedure. Because pilots are used to seeing the entire approach at one glance as on the paper charts, pilots zoomed the EAP until the entire procedure was in view, and then left the zoom at that range setting for the entire procedure. This is confirmed by Figure 4, which shows that the average map range for the different segments did not vary after the initial adjustment.

Subjective Measures

SA Probes. The SA probe data revealed that the pilots had more difficulty answering world referenced questions in the track-up mode. This is because in the track-up mode, the map rotates as pilots fly each leg of the approach, thus, the orientation of objects also changed. When asked questions such as, "Is the parallel runway east of the landing runway?", the pilots had to mentally translate the map information to determine where north was located and then relate the two objects. For the ego referenced questions, pilots had a harder time while flying a north-up map. This may be

due to the fact that in the north-up mode, the aircraft moved and at times it could be positioned upside down on the pilots' map, in which case, east was on the pilots' left and west was on the pilots' right. Therefore, questions pertaining to the location of an object with respect to the pilots' aircraft location were harder to answer.

SWORD Data. The SWORD data showed that pilots ranked the color formats as requiring less workload to accomplish the task than the monochrome formats. In the color condition, each different set of symbols was color coded, so pilots could recognize and identify navigation and geographical features easier. In the monochrome condition, there was much more cognitive workload involved in finding and identifying objects and information.

Pilots' Choice

Color Scheme Data. The monochrome format was chosen by only one pilot in the initial approach fix to final approach fix segment, and he changed to color in the final approach fix to the missed approach point segment. All other pilots chose color in both segments. Questionnaire data revealed that, even though one pilot did fly a monochrome format, all 16 preferred the color formats.

Map Orientation Data. The pilot's were evenly split in their choice of orientation during the segment from initial approach fix to final approach fix (8 chose north-up and 8 chose track-up). During the segment from final approach fix to the missed approach point, the results were virtually the same (7 chose north-up and 9 chose track-up). The reason that some of the pilots chose north-up could be due to a familiarization with the paper approach plates which are always north-up. Conversely, the reason for choosing the track-up orientation could relate to ease with which this orientation fits the pilots' mental model of where they are in space. The mental rotation involved in making the north-up orientation correspond to their current orientation is not needed in the track-up version. To clarify this idea, think of the physical rotation of a north-up map involved in turning a road map so that it corresponds to the direction of travel. Because the pilots cannot turn the electronic display, they must perform the rotation mentally.

IMPLICATIONS FOR DESIGNERS

Based on the results of this study, color versions of EAPs should be used. In addition, the designer should provide **pilot selectable** north-up and track-up versions of the EAP – a track-up/north-up switch is an easy implementation. A zoom feature should be included with the center of focus of the zoom selectable by the pilot. In order to reduce the need for frequent adjustments of the zoom control, the initial presentation of the procedure should be at a scale sufficient to show the entire approach. Also, since the zoom capability provides the opportunity to see information at different scales,

there must be upper and lower limits to the size of font and symbols used.

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